Description

Method for determining the gain spectrum of a Raman amplifier in a WDM transmission system

The invention relates to a method and an arrangement for determining the gain spectrum of a Raman amplifier in accordance with the characterizing clauses of Claims 1 and 7.

The use of distributed Raman amplification in transmission fibers permits a significant improvement in the characteristics of optical transmission systems. For example, for a given optical signal-to-noise ratio at the end of a link, the use of this technique enables the length of the individual link sections to be increased or more link sections can be bridged.

When the technique is used in WDM systems, the Raman gain should have a flat gain spectrum, so that all the channels benefit to the same extent. On the other hand, the system improvement which can be obtained is limited by the channel with the lowest gain. The higher gain of the other channels corresponds to an inefficient utilization of the pump power deployed and, if the differences are very large, can degrade their signal quality by doubled Rayleigh backscattering.

A flat gain spectrum across a wide range of wavelengths can be obtained by the use of several pumping signals at different wavelengths. However, the desired gain spectrum is achieved only for a quite particular distribution of the power at the individual pumping wavelengths. These must be adjusted for the required gain, the position of the pumping wavelengths relative to the signal wavelengths, the insertion loss between the pumping source and the transmission fiber, and the characteristics of the transmission fiber.

DT05 Rec'd PCT/PTO 22 FEB 2005

The characteristics of the transmission fiber which are relevant for the Raman amplification can have such a wide distribution from one sample to another, even for fibers of one type (SSMF, LEAF, TrueWave, ...), that there are detectable differences in the resulting gain spectrum. In addition, when the system is installed nothing is generally known about the insertion loss between the pumping source and the actual input to the transmission fiber. It is therefore only possible to set up a desired gain spectrum when the system is being commissioned if the actual gain spectrum which applies over each link section can be measured, and the pumping powers appropriately adjusted if there are deviations.

Until now there have been essentially four known methods for setting the pumping powers of the Raman sources when a system is being commissioned. The first method can be used if the system is commissioned with its maximum number of channels. In this case, the link sections are started up one after another, starting with the one immediately after the transmitter. As all the channels are already present during commissioning, they can be used as a test signal spectrum for a gain measurement. The signal spectrum at the output from the link section concerned is first measured with the Raman pumping source switched off, then the spectrum with the source switched on. The ratio of the two spectra, or the difference in the level in dB, as applicable, immediately gives the on/off gain spectrum of the Raman amplifier. An exemplary embodiment of this type is described in EP 1 130 825 A2. Here, the gain measurement is carried out as a function of a specific configuration of active channels, which is undesirable when the system is being commissioned.

Unfortunately this method can seldom be used in practice, because most systems are commissioned using only a very small number of channels, and only later are they upgraded. It would indeed be possible in principle to measure and adjust the gain spectrum using

only the signal channels already initially available, since the gain in the case of the channels which are still missing plays no part. It would then be necessary to remeasure and tune the gain spectrum before or during the commissioning of additional channels. The switching off of the Raman pumping source which this requires would

disrupt the transmission of the channels which are already present. For this reason, even during the initial commissioning of the system the gain spectrum should be measured and tuned for all the channels which will be present at maximum capacity.

In the case of the second known method for adjusting the pump powers, those channels which are not present at initial commissioning are replaced by a laser source with tunable wavelength. The determination of the signal spectrum at the output from the link section with the Raman pumping source switched off or on, as appropriate, thus requires many individual measurements, between which the tunable laser source must be switched over to the next channel. Apart from requiring a significantly longer measurement time, the method also requires a facility for communicating with the source, so that the latter can be informed when it should set which wavelength. In addition, the preparation of the source and the coupling of its output signal into the transmission system can present problems.

In order to be able to forgo a tunable laser source, a third method for the measurement of the gain spectrum has been proposed, which manages completely without a test signal at the input to the link section. This method utilizes the effect that the stimulated emission which is responsible for the gain is invariably accompanied by the generation of spontaneous emissions. For this reason, the spectrum of the ASE generated by the Raman amplifier is measured, and an attempt made to calculate the gain spectrum from this. Since the relationship between the gain spectrum and the spectrum of the ASE is very complex for distributed Raman amplifiers, the calculation is very resource intensive and error-prone.

The fourth method proposed for adjusting the pumping powers of the Raman pumping sources does completely without a measurement of the gain spectrum, and adjusts the pumping powers solely by reference to

the specified fiber type for the transmission fiber. Since the method therefore has no knowledge of either the exact fiber characteristics or the insertion loss between the pumping source and the transmission fiber, the resulting gain spectrum can deviate significantly from that actually desired.

Examples of the state of the art, in which some of the methods itemized above are used, are set out below.

WO 00/73826 A2 presents an optical transmission system which has various amplifier units connected in series. The amplifier functions are checked either in operation or by means of supplementary units by gain measurements at the wavelength of the signal, and the pumping powers are adjusted correspondingly. For test measurements of the amplifier gain, use is made of both broadband and narrowband light sources as the ASE source, depending on the number of channels to be investigated.

US 2002/0071173 A1 and US 2002/0044336 A1 also show optical amplifier units in a transmission link, which can be controlled through the pumping power, for which in each case a Raman amplifier is put in circuit upstream from the optical fiber amplifier. In US 2002/0071173 A1, the amplifier contains a wavelength-dependent tunable filter. In order to obtain a flat gain spectrum, the gain spectra of the amplifier unit are checked and the filter adjusted accordingly. In US 2002/0044336 A1, the amplifier module contains a unit which determines whether the input signal has been interrupted due to noise effects in the Raman amplifier. The pumping power of the Raman source is adjusted according to the signal detection, by which means the noise level can also be regulated.

US 2002/0054733A1 discloses a typical transmission section with a Raman amplifier and an optical fiber amplifier as a booster,

upstream from the Raman amplifier, for which the Raman gain spectrum is determined by a comparison of the spectrum of the signals transmitted over the active channels against a stored spectrum. Using a regulating unit, the power of the pumping source for the Raman amplifier is varied in such a way that minimal deviations occur between the spectra which are compared, from which the Raman gain can be derived.

It is the object of the invention to specify a method, and in addition an arrangement, for the determination of the gain spectrum which enable the powers of the pumping sources for the Raman amplifier to be simply adjusted, and with which the disadvantages mentioned above are avoided.

This object is achieved, in respect of the method, by a method with the characteristics of Claim 1, and in respect of the device by an arrangement with the characteristics of Claim 7.

Advantageous developments of the invention are specified in the subclaims.

The proposed method in accordance with the invention uses as the test signal the amplified spontaneous emission, ASE, which is generated by the optical amplifiers present in the system, for example Erbium-doped fiber amplifiers, EDFAs. Since the fiber amplifiers, the EDFAs, must have a flat gain spectrum over the entire range of signal wavelengths, they will also generate ASE over the entire wavelength range in which the gain spectrum of the distributed Raman amplifiers must be measured using a broadband pumping source. The ASE spectrum has a different graph from the gain spectrum of the EDFA fiber amplifiers. However, the exact shape of the ASE spectrum for the EDFA fiber amplifiers does not affect the measurement of the gain of the Raman amplifiers. The Raman gain spectrum which is to be measured is given by the ratio of spectra at the output from the

link section with the Raman pumping source switched off or on, as applicable, and does not depend on the shape of the individual

spectra.

In principle, the use of the ASE for the EDFA fiber amplifiers would permit the gain spectrum of the distributed Raman amplifiers to be measured with absolutely no signal channels being present. For the purpose of protecting the EDFA fiber amplifiers, WDM transmission systems which have been developed to the full product stage commonly provide safeguards to prevent the EDFA fiber amplifiers being switched on when there are no channels present. Advantageously, the presence of signal channels does not disrupt the proposed method, because the ratio of the spectra at the exit from the fiber can also be determined with any arbitrary number of channels.

One problem in measuring the gain spectrum is presented by the ASE generated by the distributed Raman amplifier itself. This only arises with the pumping source switched on, and can therefore falsify the result of the measurements. The ASE generated by the distributed Raman amplifiers themselves can be determined by a third measurement, and calculated out. To do so, an additional measurement is made of the spectrum at the exit from the fiber section, with the Raman pumping source switched on but with the EDFA fiber amplifier before the link section switched off. The spectral components observed in this case must be subtracted from the measurement made with the pumping source switched on and the EDFA fiber amplifier switched on.

The interference effect of the ASE generated by the Raman amplifier itself is greater the nearer the link section lies to the input into the overall system. In the first link sections, the power of the ASE generated by the EDFA fiber amplifiers is still comparatively small. Only in the link sections further downstream does the ASE, generated in the preceding amplifiers and used as the measurement signal, become greater than the component which the Raman amplifier contributes in the link section under consideration.

The accuracy of the measurement of the gain spectra in the front

link sections can be increased by an artifice. When operated in regular mode, the EDFA fiber amplifier (booster) before the first link section generates comparatively little ASE, because it works with a high input level. Modern transmission systems generally provide VOAs (variable optical attenuators), adjustable attenuation elements with which the level of the individual transmitters can be balanced. These VOA attenuation elements can also be utilized to reduce the input level into the booster. With lower input levels the boosters, which are regulated to give constant output power, generate more ASE. In this way it is possible to select the ASE attributable to the booster so that it is stronger than that from the Raman amplifier.

If the WDM transmission system works with several signal bands, which are processed in separate EDFA fiber amplifiers or other discrete amplifiers, the ASE spectra of these amplifiers can be used for the measurement of the gain spectrum of the distributed Raman amplifier. Since the distributed Raman amplifier must then process all the signal bands, the gain measurement should extend across them. Each of the discrete amplifiers does indeed generate ASE in only one band. However, the aggregate signal from the ASE for all the discrete amplifiers does cover the entire range of signal wavelengths. It is advantageously possible to arrange several fiber amplifiers or Raman amplifiers in a section of the transmission link to amplify a WDM signal in different spectral ranges, whereby the gain spectrum of one of the Raman amplifiers is determined using the method in accordance with the invention.

An exemplary embodiment of the invention is explained in more detail below by reference to the drawing.

This shows:

Fig.1: an arrangement for carrying out the method in accordance with the invention in a first transmission section.

As an exemplary embodiment, consider an arrangement as shown in **Fig. 1** for carrying out the method in accordance with the invention, which shows a first transmission section as a segment of a WDM transmission system. Connected to this transmission section is a Raman amplifier, which has a pumping source PQ with several pumping signals. For the purpose of generating the Raman pump radiation, the pumping source PQ at the end of the link section uses four laser diodes. Pumping signals from the pumping source PQ are combined together with the help of a wavelength-selective multiplexer MUX. The laser diodes generate signals with wavelengths of 1423 nm, 1436 nm, 1453 nm and 1467 nm. A band filter KO1 feeds the pump signals into the signal path or into an OWG transmission fiber, as applicable, in the opposite direction from the direction of propagation of the transmitted signals.

Downstream from the band filter KO1 of the pumping source PQ in the signal path is a coupler KO2. With the help of an optical spectrum analyzer OSA connected to the coupler KO2, the spectrum at the output from the link section can be measured.
Upstream from the OWG transmission fiber is an amplifier, as a booster BO. The amplifier used is an Erbium-doped fiber amplifier, EDFA1. However, other optical amplifiers such as semiconductor amplifiers, Thylium-doped fiber amplifiers, or discrete Raman amplifiers, could be used as the booster BO. Upstream from the booster BO is a multiplexer MUX2 for combining the channels which are to be transmitted in a WDM signal. Further optical amplifiers EDFA2, or generally designated EDFAs = EDFA1, EDFA2, ..., are connected along the transmission link downstream from the coupler KO2.

Contained in this arrangement is a control device SE for switching the pumping sources of the fiber amplifier and the Raman amplifier on and off.

During commissioning there should be, in the example chosen, only a single channel S1 outbound from a transmission unit TX, with a downstream adjustable attenuation element, VOA. This single channel S1 is sufficient to disable the safety shutdown of the fiber amplifier EDFA. After the transmitter TX has been switched on, the attenuation element VOA is initially adjusted so that the channel S1 reaches its set level at the input to the booster BO. After this, the booster BO is switched on. Then, the insertion attenuation of the attenuation element VOA is increased up to the point when the booster BO produces sufficiently amplified spontaneous emission, ASE.

During a first measurement of the spectrum SP1 at the output from the section link, made using the optical spectrum analyzer OSA, the Raman pumping source remains switched off. After this, the booster BO is switched off and a second spectrum SP2 is measured with the Raman pumping source PQ switched on. For a third measurement of a third spectrum SP3, the booster BO is switched on again. For the purpose of calculating the gain spectrum of the Raman amplifier, the second spectrum SP2 is first subtracted from the third spectrum SP3 (both spectra in W or W/Hz, as applicable), and this difference is then divided by the first spectrum SP1 (again in W or W/Hz, as applicable). This ratio, (SP3-SP2) / SP1, corresponds to the spectrum of the on/off gain of the Raman amplifier. Connected to the optical spectrum analyzer OSA are a unit EE, for analyzing the spectra recorded by the optical spectrum analyzer OSA, and a regulator RE for controlling the spectral power components of the pumping source PQ to re-regulate the gain spectrum GS. The analysis unit EE is also connected to the control device SE for the purpose of synchronizing the switching of each of the amplifiers, on and off, while the desired spectra are recorded.

Depending on the configuration of the transmission links, it may be possible to ignore the amplified spontaneous emission from the Raman amplifier, i.e. to save the measurement of the second spectrum SP2.

In this case, only two measurements are carried out, with the pumping source switched on and off for the Raman amplifier, and the optical amplifier switched on. In this case, the gain spectrum GS is determined as the ratio SP3/SP1 of the third spectrum to the first.

After level adjustment for the Raman amplifier in the first transmission link section, the following fiber amplifier EDFA2 in the second link section is put into operation. Gain measurement for the Raman amplifier in the second link section can then be carried out. The first spectrum SP1 is again measured with the pumping source switched off, the second spectrum SP2 with the pumping source switched on and EDFA2 which precedes the link section switched off, and the third spectrum SP3 with the Raman pumping source switched on and EDFA2 switched on. The calculation of the gain spectrum is carried out as described above. The gain spectra for the following link sections are determined in the same way.